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The inner radial gradient of chemical abundance in the CALIFA galaxies

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Abstract. The study of chemical evolution has great importance for understanding the evolution of the universe. Models and observations indicate an inside-out scenario for the formation of spiral galaxy disks. The chemical abundance gradients in some cases deviate from a simple straight line with a negative slope, presenting an inner drop and/or an outer flattening, mainly for massive galaxies. In this work, the oxygen abundance gradients of spiral galaxies were analyzed using Calar Alto Legacy Integral Field Area (CALIFA) survey observations. The profiles of oxygen gradients in HII regions belonging to the disks of spiral galaxies were analyzed, applying an automatic fit procedure for the abundance gradients to identify the deviations of the gradients in the inners regions of the spiral disks. No relationships were found with the presence of the bar in spiral galaxies, in such a way that the presence of the bar could interfere with the abundance gradient. A possible influence of the bulge on the inners drops in abundance gradients is being analyzed, but a conclusive result has not yet been obtained. Establishing a possible relationship between the bulge and the inner deop becomes important in obtaining more information about the abundance gradients, enabling a better understanding of the chemical evolution of galaxies that present these deviations in the gradients.

Resumo. O estudo de evolução química possui grande importância para a compreensão da evolução do universo. Modelos e observações indicam um cenário *inside-out* para a formação dos discos de galáxias espirais. Os gradientes de abundâncias químicas em alguns casos desviam de uma simples reta com inclinação negativa, apresentando uma queda interna e/ou um achatamento externo, principalmente para galáxias de maior massa. Neste trabalho, foram analisados os gradientes de abundância de oxigênio de galáxias espirais com observações do *Calar Alto Legacy Integral Field Area* (CALIFA) *survey*. Foram analisados os perfis dos gradientes de oxigênio em regiões HII pertencentes aos discos de galáxias espirais, aplicando-se um procedimento automático de ajustes de gradientes de abundâncias para identificar os desvios dos gradientes nas regiões internas dos discos espirais. Não foram encontradas relações com a presença da barra nas galáxias espirais, de tal forma que a presença da barra pudesse interferir no gradiente de abundância. Está sendo analisado uma possível influência do bojo nas quedas internas dos gradientes de abundância, porém ainda não foi obtido um resultado conclusivo. Estabelecer uma possível relação do bojo com a queda interna se torna importante na obtenção de maiores informações sobre o gradiente de abundância, possibilitando uma maior compreensão da evolução química de galáxias que apresentam esses desvios nos gradientes.

Keywords. HII regions – Galaxy: abundances – Galaxy: bulge

1. Introduction

The study of the chemical evolution in spiral galaxies is of great importance for understanding the evolution of the universe. Deviate in the abundance gradient are observed in some galaxies, mainly in the more massive ones, whose gradient present an inner drop and/or outer flattening in the main negative slope. With the analysis of star formation region (HII regions) we obtained the oxygen abundance gradient using the O3N2 (Alloin et al. 1979) index and the calibration PP04 of the Pettini & Pagel (2004) of 182 spiral galaxies observed with the survey CALIFA with distribution of the morphological type and of the stellar mass shown in Fig. 1. We performed a statistical analysis with the gradients of the galaxies who presented an inner drop and tried to get a relationship with the physical properties of galaxies, in particular, with the bulge.

2. Determination of the gradients

The information for selection of sample were obtained in the third data release of the survey CALIFA in Sánchez et al. (2016). The spectroscopic data to obtain the oxygen abundance gradient were obtained in Espinosa-Ponce et al. (2020) being that the radial distributions were normalized by the effective radius of the galaxy. The fit of abundance gradient were performed automatically and the details can be found in Pilgrim (2021). The fit is performed considering that there may be one or two breaks in the gradient as shown in Fig. 2.

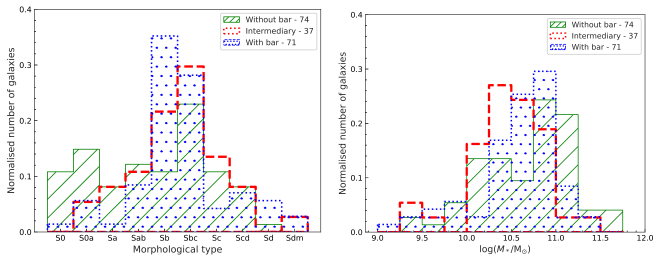

Figure 1. Distribution of the morphological type and of the stellar mass for galaxies of our sample, according with the presence or not of bar.

3. Results

From 182 galaxies, 36 galaxies presented an inner drop in the gradient, with mass $\log(M/M_\odot) > 10.2$ and we found a mean value of (0.7 ± 0.2) r_e for the position in which it occurs the inner drop. This result differs of the obtained by Sánchez-Menguiano et al. (2016) and Sánchez-Menguiano et al. (2018), which got a mean value of 0.5 r_e. As in Sánchez-Menguiano et al. (2016) and Sánchez-Menguiano et al. (2018), we did not find dependency

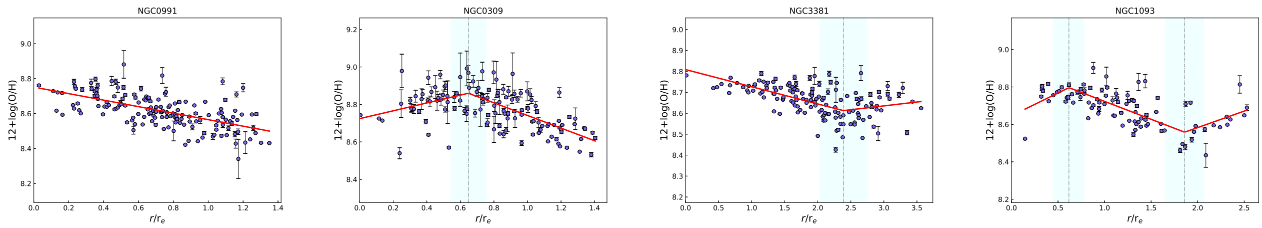

Figure 2. Some fit examples for the oxygen abundance gradient: NGC0991 a simple linear fit; NGC0309 a fit with an inner drop; NGC3381 a fit with an outer flattening; and NGC1093 a fit with both an inner drop and an outer flattening.

with the presence of bar in the occurrence of the inner drop in the gradient. These relationships are shown in Fig 3.

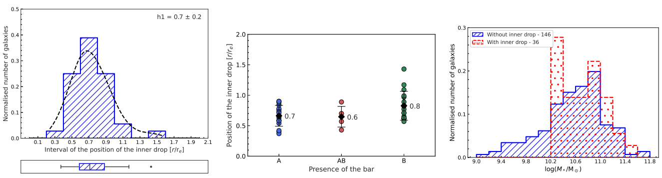

Figure 3. From left to right: Distribution of the number of galaxies according with the position in which occurs the inner drop. Relationship of the presence or not of the bar with the position of the inner drop, being "A" without bar, "AB" intermediary and "B" with bar. Mass of galaxies according with the presence or not of the inner drop.

We use the data from multi-component photometric decomposition of the galaxies as performed by Méndez-Abreu et al. (2017) in order to obtain the bulge parameters. With the effective radius of the bulge we calculated the dispersion velocity of the bulge according to Sani et al. (2011) and then we obtained the mass of the bulge according to Beifiori et al. (2011). With the parameters of the galaxy and the bulge, we performed an analysis with the adjustment coefficients, as shown in Fig. 4. We verify a trend in the decrease of the linear coefficient b0 and in the increase of the angular coefficients a1 and a2 with the increase in mass.

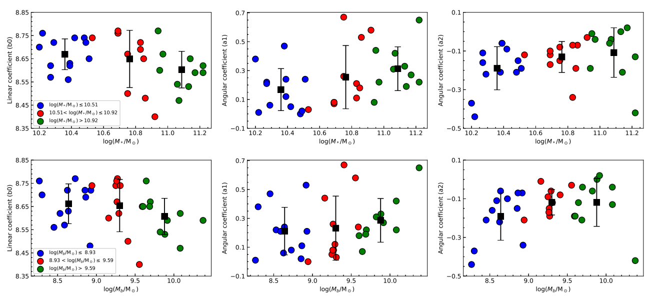

Figure 4. The upper panels refer to relations with the galaxies masses, while the bottom ones with the bulge masses. From left to right, b0 is the linear coefficient that intercepts the axis of the oxygen abundance, a1 is the angular coefficient of the fit referent to the inner drop and a2 is the angular coefficient of the main negative gradient.

We determine the mean abundance in the effective radius of the galaxies that showed the inner drop and apply an offset in the distribution of the each galaxy, normalizing it according Sánchez et al. (2013). The trend showed in the Fig. 4 is confirmed in the Fig. 5. We see that, when occurs the inner drop, the more massive galaxies have lower oxygen abundances in the central region, with a more inclined gradient. On the contrary, less massive galaxies have higher oxygen abundances in the central region and a less inclined gradient.

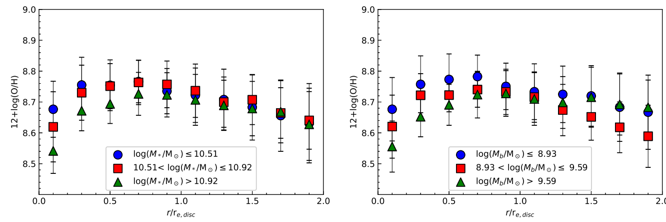

Figure 5. Mean oxygen abundances in bins of 0.2 r/r_e for galaxies that present an inner drop, separated by different intervals of mass: stellar mass (left) and bulge mass (right).

4. Conclusion

We found a relationship between the galactic mass and the oxygen distribution when occur the inner drop. The same relationship is observed with the bulge mass. However, the more massive the galaxy, the more massive tends to be the bulge. The fact that the mean position in which the inner drop occurs differs from the values obtained in the literature may be related with the adopted method to fit the gradients used in this work. We did not find any relationship with some physical property of the bulge that could explain those deviations in the gradients. Until the moment, we can only verify that the mass of galaxy (and consequently of the bulge) have a relationship with the inner drop. This inner drop tends to occur in more massive galaxies, with $\log(M/\mathrm{M}_\odot) > 10.2$ and the more massive the galaxy, the steeper the gradient tends to be, with respect to the inner drop.

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